Nutrient Removal in much of Utah-- Is it a Gigantic Waste!

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First—A quick look at "eutrophication"

--Since this is the concept behind the Utah nutrient debate

Eutrophication:

Increasing aquatic plant growth and overall biological productivity in a water body over time to a state where significant water quality problems result.

<u>Sometimes</u> eutrophication results in marked losses in “water quality”.

The concern: Natural eutrophication from a pristine lake to a swamp often takes hundreds or thousands of years, or more, but human activities often accelerate the natural process.

When it is a problem, it is normally driven by too much algae!

Trophic level classification for lakes:

- Oligotrophic (low bio-productivity, clear)
- Mesotrophic (moderate " ,slightly turbid)
- Eutrophic (high " , turbid)
- Hyper eutrophic (very high " , very turbid)

Turbidity as used here is --biological turbidity

- An oligotrophic lake

- A mesotrophic lake

- Eutrophic lakes

- Hyper-eutrophic lakes

- Most lakes eventually become marshland—then wet meadows—then “basin” land

Problems that <u>might</u> occur in lakes, more so in eutrophic lakes:

- *Turbidity: Turbid water from prolific algal and other biological growth*
- *Aesthetics: Significant floating algae and other bio-debris*
- *Debris Accumulation: Unsightly bio-debris along shorelines*
- *Oxygen Loss: "Normal" biota stressed or killed*
- *Mucky Bottom: "Mucky", often septic, conditions at the bottom*
- *Bad odors: Nasty odors from time to time around the lake*
- *Nuisance Insects: Swarms of insects and aquatic bugs*
- *Coarser Fish: Conditions that favor "coarser" fish and other aquatic life*
- *Toxics: "Troublesome" residual decay compounds in the water*

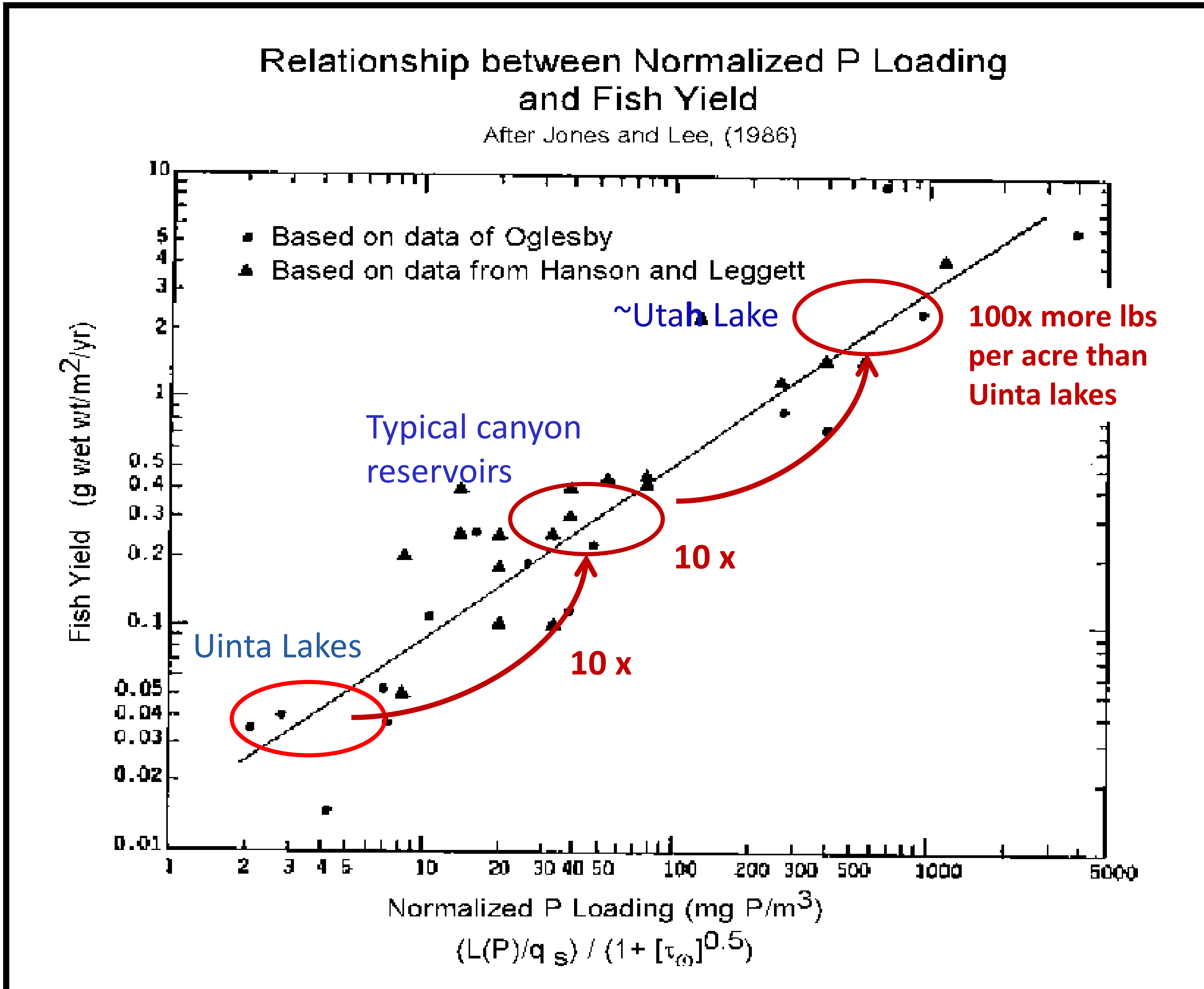
Note—Most "problems" in eutrophic lakes (and rivers) relate to on-site aesthetics and recreation—and generally not to primary water quality concerns of disease and filth.

That is, most eutrophic issues relate to

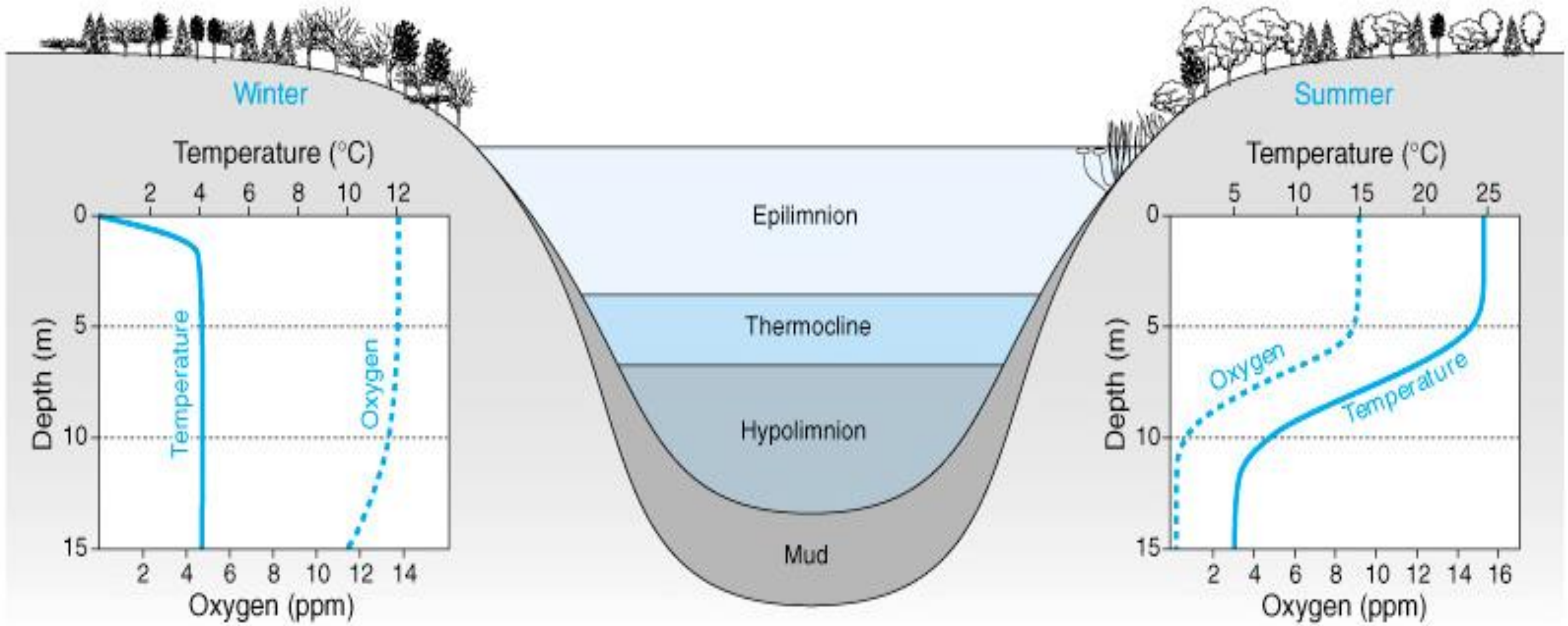
- **"How pristine and scenic is the lake?"**
- **"does it look good and smell okay?"**

Natural lakes have some, to all, of the problems associated with "eutrophic" conditions.

Rivers/steams can also have algae-caused water quality problems but usually to a lesser extent that lakes do.


Relationship between Normalized P Loading and Fish Yield
After Jones and Lee, (1986)
Based on data of Oglesby
Based on data from Hanson and Leggett
~Utah Lake
100x more lbs per acre than Uinta lakes
Typical canyon reservoirs
10 x
10 x
Uinta Lakes
Fish Yield (g wet wt/m2/yr)
10
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
0.05
0.04
0.03
0.02
0.01
1
2
3
4
5
10
20
30
40
50
100
200
300
500
1000
5000
Normalized P Loading (mg P/m3)
(L(P)/q s) / (1+ [τω]0.5)

"Deep" Eutrophic Lake



Strawberry Reservoir--1975

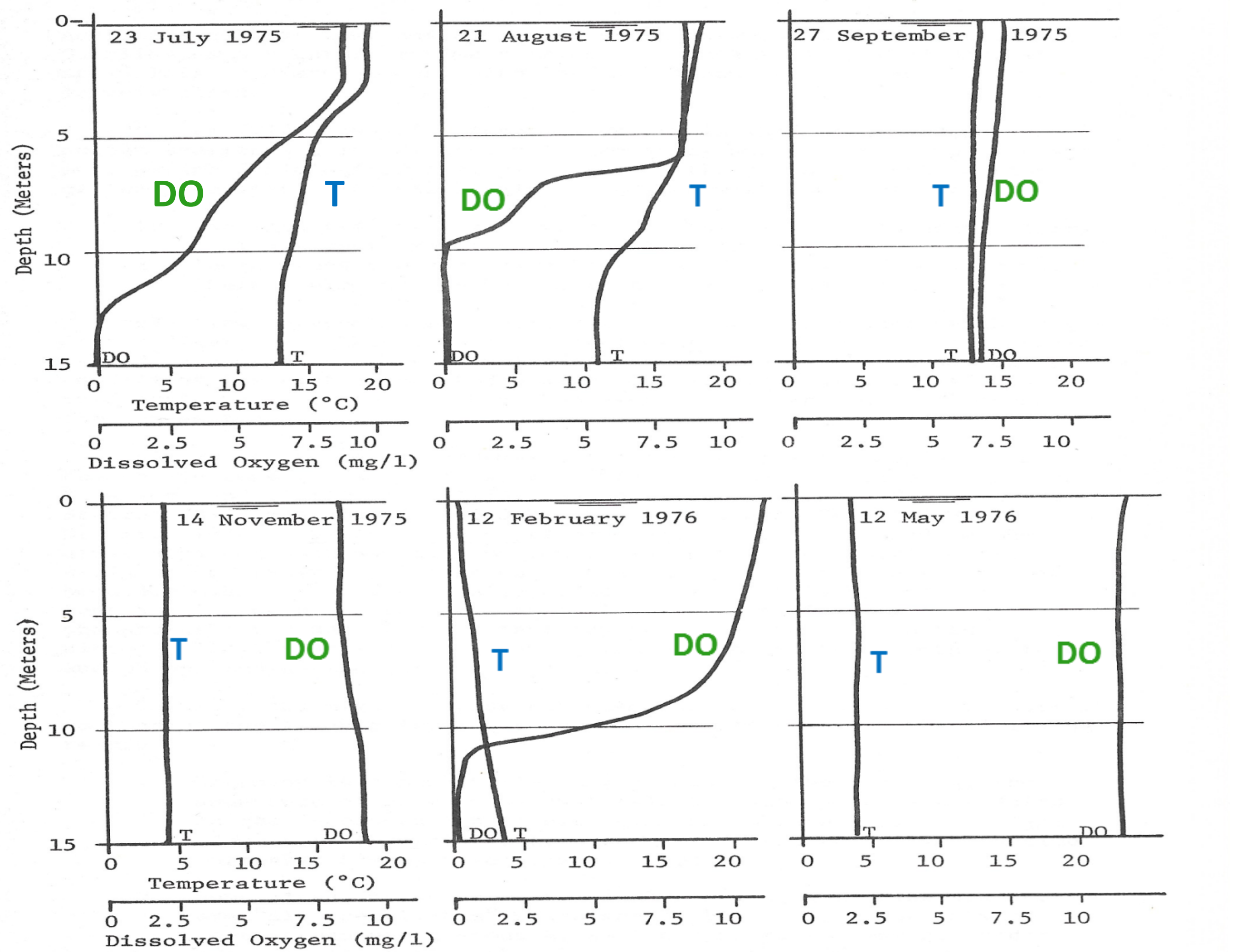


Figure 7.11. Strawberry Reservoir – Observed Temperature and Oxygen Profiles at Station SB-3, 23 July 1975 to 12 May 1976.

How many of these problems occur in Utah Lake?

• *Turbidity:*	*mainly mineral turbidity*
• *Aesthetics:*	*moderate*
• *Debris Accum.*	*moderate*
• *Oxygen Loss:*	*rare*
• *Mucky Bottom:*	*mainly mineral not organic*
• *Bad odors:*	*moderate*
• *Insects:*	*yes*
• *Coarser Fish:*	*yes*
• *Toxics:*	*low*

All in all:

Utah Lake has good water quality as compared to most eutrophic, basin-bottom systems!

Most arid and semi-arid, basin-bottom lakes are eutrophic to hyper eutrophic and rather undesirable for most recreation.

Now-

How a quick look at growth factors involved in algae growth.

Main factors determining plant growth:

- Light (Amt. of sunshine reaching the algae)
- Nutrients (phos., nitrogen, other vitamins and minerals)
- Temperature
- Toxicants
- Time
- Variability in factors
- Competition
- Grazing/Harvesting

Utah Lake's natural condition:

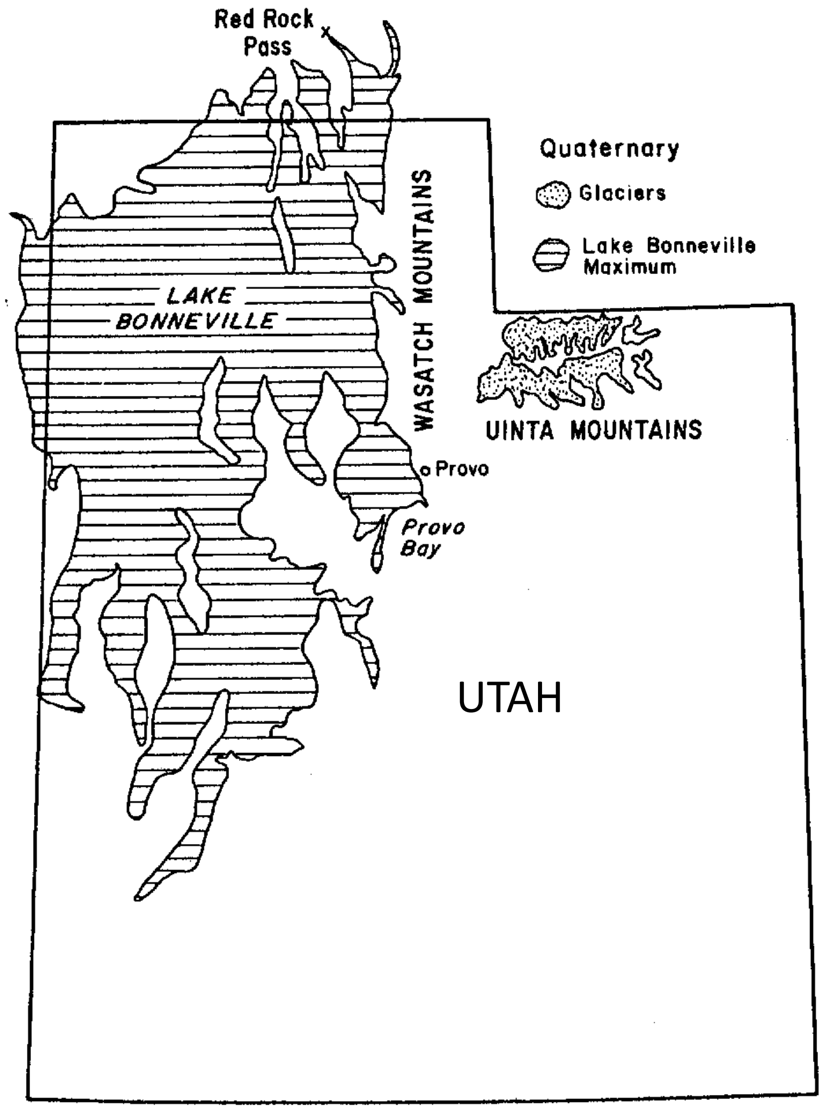
- shallow
- slightly saline
- turbid
- eutrophic
- in semi-arid region

Indications are that the lake has been essentially this way since it stabilized after Lake Bonneville last receded 8000 to10,000 yrs ago.

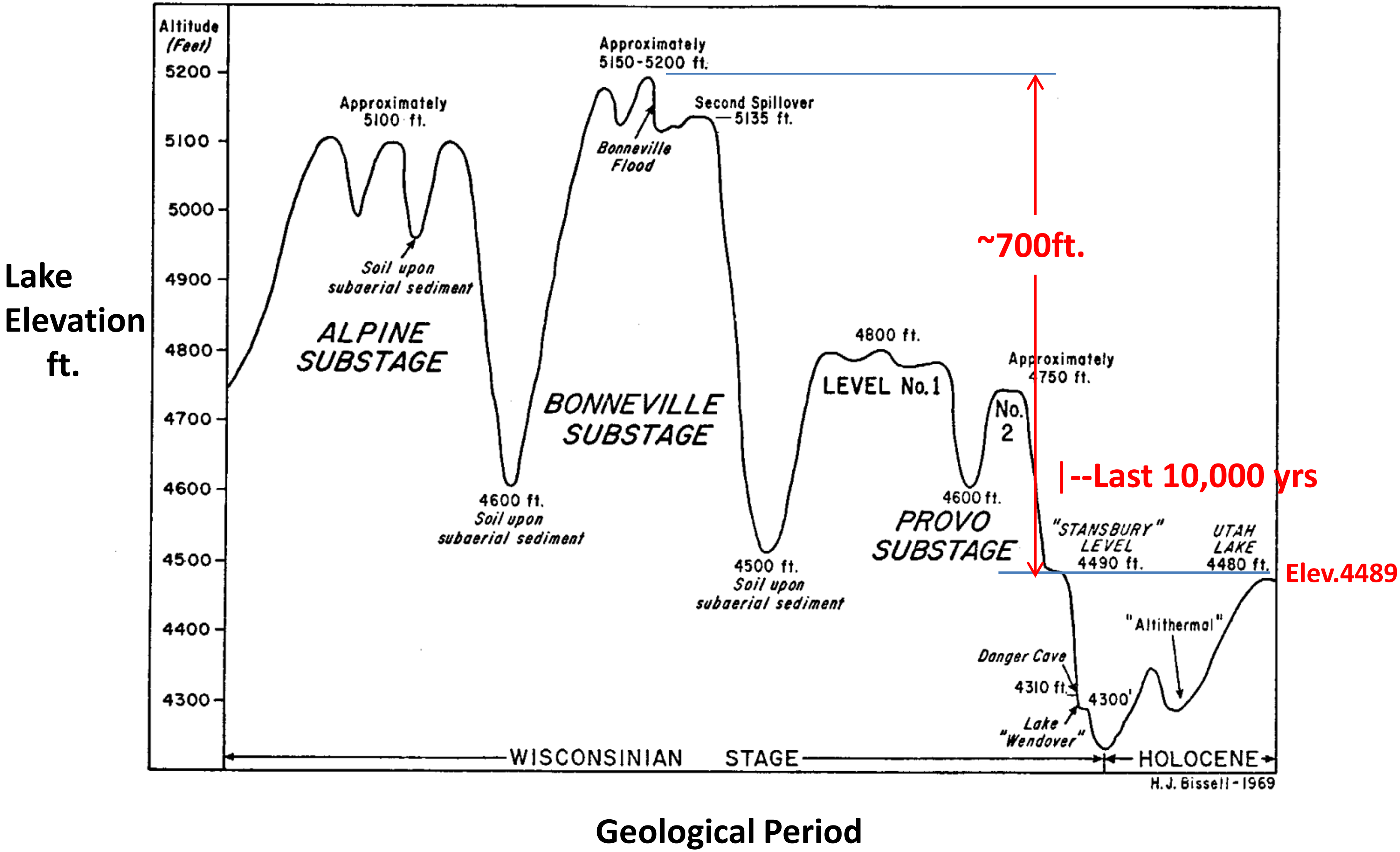
Utah Lake's Origins

– Lake Bonneville

(A few hundred thousand years ago)



Utah Lake's Origin: --Remnant of Lake Bonneville.



Utah Lake during a windy period

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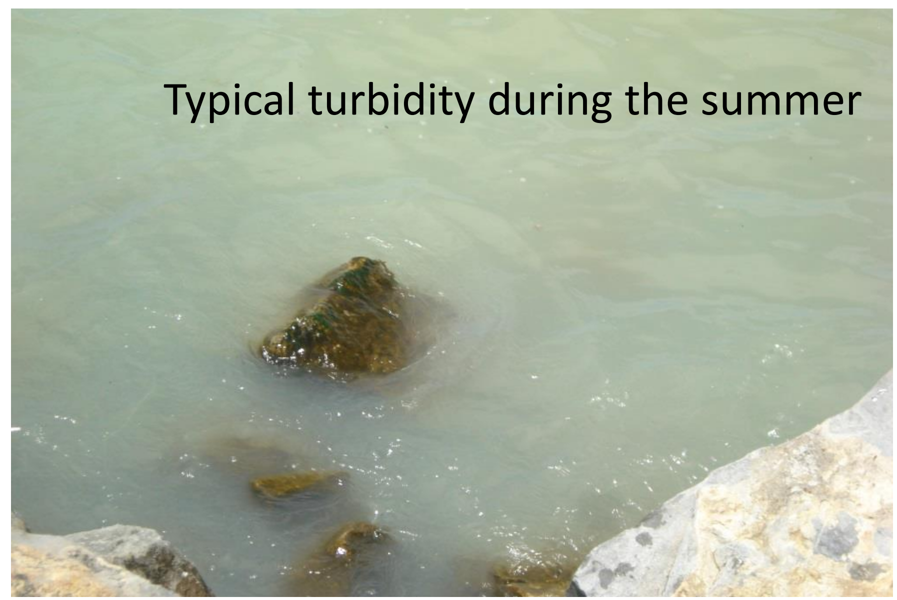
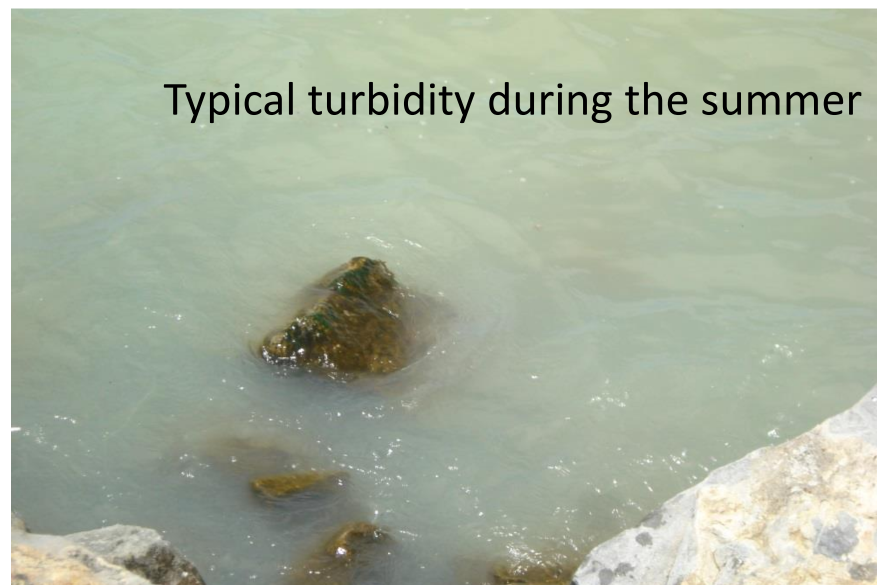
Turbidity in Utah Lake



Typical turbidity during the summer

Turbidity in Utah Lake

Why can't it be like this all of the time?



Typical turbidity during the summer

Table 1. Utah Lake Inflows: Avg Salt and Water Quantities for 2009-2013.

I. INFLOW	Flow		Percent of Inflowing Salts								% of Nutrients		
1. **Surface**	af/yr	%	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
a. Mtn Strms	287862.	52.0	24.3	12.9	42.5	28.3	14.5	10.0	39.6	19.6	7.0	14.5	4.2
b. WWTP	53126.	9.6	11.0	12.9	8.9	9.0	14.2	14.3	10.4	6.3	79.	54.7	85.5
c. Main L-other	77799.	14.1	17.3	12.4	16.6	24.1	15.2	9.8	22.1	27.8	7.6	17.5	6.2
d. Provo B-other	53232.	9.6	9.8	4.8	13.0	11.8	7.6	4.6	12.1	11.4	1.6	5.5	1.3
e. Gosh. B-other	23073.	4.2	14.0	24.1	3.2	10.1	17.5	23.7	3.4	14.3	1.6	2.3	1.5
1. Subtotal:	495092.	89.5	76.4	67.1	84.2	83.3	69.0	62.5	87.6	79.4	**96.8**	**94.6**	**98.7**
2. **Fresh Grnd water**													
a. Main L-gw	31640.	5.7	3.3	1.9	3.9	5.2	3.4	1.7	5.2	2.7	0.4	1.8	0.3
b. Gosh. B-gw	11531.	2.1	3.0	3.4	2.1	3.9	4.7	3.8	2.3	2.9	0.1	0.7	0.1
2. Subtotal:	43171.	7.8	6.2	5.2	6.0	9.0	8.0	5.4	7.5	5.6	0.5	2.4	0.4
3. **Thermal/Mineral GW**													
a. Main-min sprs	13957.	2.5	16.7	26.8	9.5	7.0	22.6	31.1	4.6	14.5	0.3	0.1	0.3
b. Gosh. B-m sprs	787.	0.1	0.3	0.6	0.1	0.1	0.4	0.5	0.1	0.4	0.0	0.0	0.0
3. Subtotal:	14744.	2.7	17.1	27.4	9.6	7.2	23.0	31.6	4.7	14.9	0.4	0.1	0.3
1,2& 3 subtot	553007.	100.0	99.7	99.8	99.8	99.5	100.0	99.5	99.9	99.9	97.7	97.0	99.4
4. **Precipitation**													
a. Main Lake	52884.	b. Provo Bay 8633. c. Goshen Bay 31649.											
4.Total Precip	93164.		0.3	0.2	0.2	0.5	0.1	0.5	0.1	0.1	2.3	3.0	0.6
			100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

INFLOW TOTAL 646,171.

II. **Outflow.**

1. **Jordan River 336,045.**

2. **Evaporation**

a. Main Lake 218073. b. Provo Bay 32133. c. Goshen Bay 92602.

2. Subtotal **332,808.**

II. Outflow tot 668853.

Lake Storage -22682.

Net 646171.

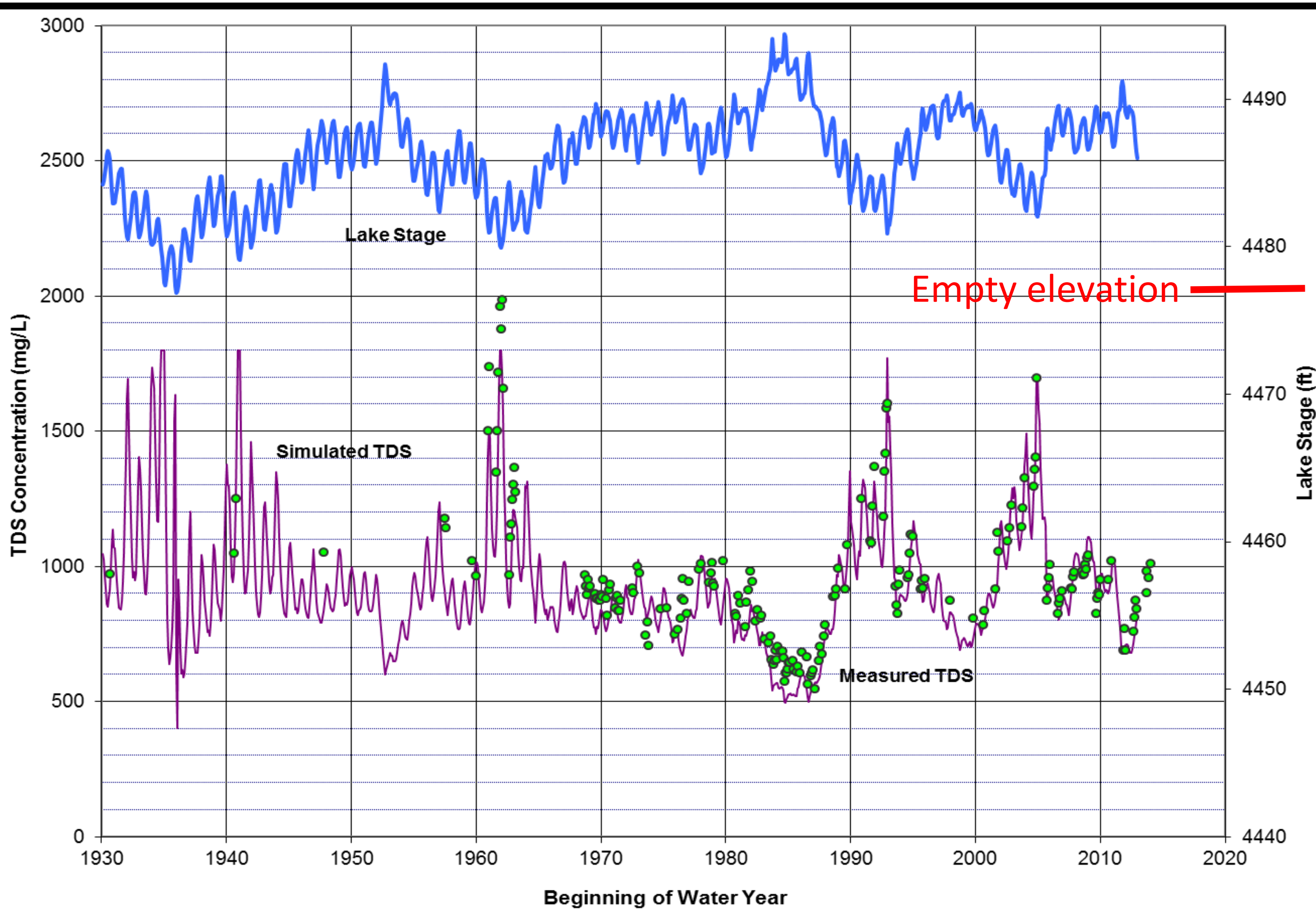
	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
Ratio: salts out/salts in:	85.	108.	39.	107.	109.	110.	54.	110.	**9.4**	**17.1**	**9.4**

Approx. corrected

Table 1. Utah Lake Inflows: Avg Salt and Water Quantities for 2009-2013.

	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
Percentage: (salts out/salts in)	**79**	100	**36**	100	100	100	**50**	100	**9**	**16**	9

The Ca and HCO3 precipitated averages about 100,000 tons /yr
--this is about 2”/100 yr over the full-lake area!
--or about 200” (18 ft) in 10,000 yrs.



Historical Total Dissolved Solids and Water Levels in Utah Lake

Table 2 . Utah Lake nutrient inflows and outflow—2009-2013.

			Nutrient LoadIngs -- ton/Yr			
			TP		DN	DP
1. **Surface Inflow**	af/yr	%		%		
a. Mtn Strms	287862.	52.0	19	**7**	311	10
b. POTW	53126.	9.6	215	**79**	1174	196
c. Main L-other	77799.	14.1	21	**8**	375	14
d. Provo B-other	53232.	9.	4	**1**	118	3
e. Gosh. B-other	23073.	4.2	4	**1**	50	3
1. Subtotal:	495092.	89.5	264	**97**	2028	226
2. **Fresh Grnd water**						
Subtotal:	43171.	7.8	1		51	1
3. **Thermal/Mineral GW**						
Subtotal:	14744.	2.7	1		2	2
1,2& 3 subtot	553007.	100.0				
4. **Precipitation (rain and snow)**						
Total Precip	93164.		6	**2.2**	64	1
INFLOW TOTAL	646171.		**272**		**2145**	**229**
II. **Outflow.**						
1. **Jordan River**	33604.		**26**	**9.6**	**367**	**22**
2. **Evaporation**	332808.					
II. Outflow tot	668853.					
Change in Storage	-22682.		TP	%	DN	DP
Net	646171.		**26**	**9.6**	**367**	**22**
Lost--precipitated in the Lake			**246**	**90.4**	**1778**	**207**

these values are under final review and may change slightly

Table 3. Nutrient Loadings to Utah Lake by water year, 2009 – 2013

Water Year	Phos. tons/yr	SRP tons/yr	Nitrogen tons/yr
2009	277	232	2235
2010	257	219	1813
2011	327	267	2872
2012	247	211	1812
2013	252	216	1816
Average	**272**	**229**	**2145**

Utah Lake has high natural high turbidity, Why?

1. In-lake chemical precipitation of calcium-carbonate-silica-phosphorus (largely clayey Marls) adds a natural, cloudy, mineral turbidity. (removes some 100,000 tons/yr--this is an avg. of about 2 in. of bottom sediments per 100 yrs.—3” or 4” in deeper areas)

Secchi Disk readings indexes light penetration.

(Typically at 2x to 3x the Secchi depth there isn’t enough light for appreciable algae growth—During the summer, Secchi depths in Utah Lake are usually less than 1 ft. --indicating very high turbidity and very limited algae growth ocurring below 1 to 2 ft deep.)

Light limitation Cont.

Avg. depth of Lake is about 9 ft. Frequent waves stir up and re-suspend the flocculent, precipitated sediments resulting in turbid, light-limiting, algae-growth conditions most of the time.

Ans: Overall, Utah Lake algae growth is likely light-limited.

Big Issue: Since the State is requiring nutrient removal

- Might P & N possibly be limiting or be made limiting?
- In other words—will it do any good?

To answer this question, consider:

1. What are the actual in-lake conditions?

2. What do predictive Trophic Level models indicate?

1. What are the actual in-lake trophic conditions?

Carlson Trophic State Index

(In-lake conditions—normally use the average of summer conditions)

Utah Lake in red:

Trophic Index	Chl a (ug/l)	P (ug/l)	Secchi Disk (m)	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	**20—60**	**25—100**	2—0.5	**Eutrophic**
70—100+	56—155+	96—384+	**0.5—<0.25**	**Hyper-eutrophic**

The hyper-eutrophic indication from Secchi Disk readings is a false indicator for Utah Lake since the low values are mainly due to mineral turbidity—not biological turbidity.

Conclusion:

- Based on observations/samples:

  the actual biological status of Utah Lake is eutrophic

2. What do the predictive trophic level models predict?

Larsen-Mercier Trophic State Model

(developed by EPA scientists—improvement on the original Vollenweider Model.)

Model uses:

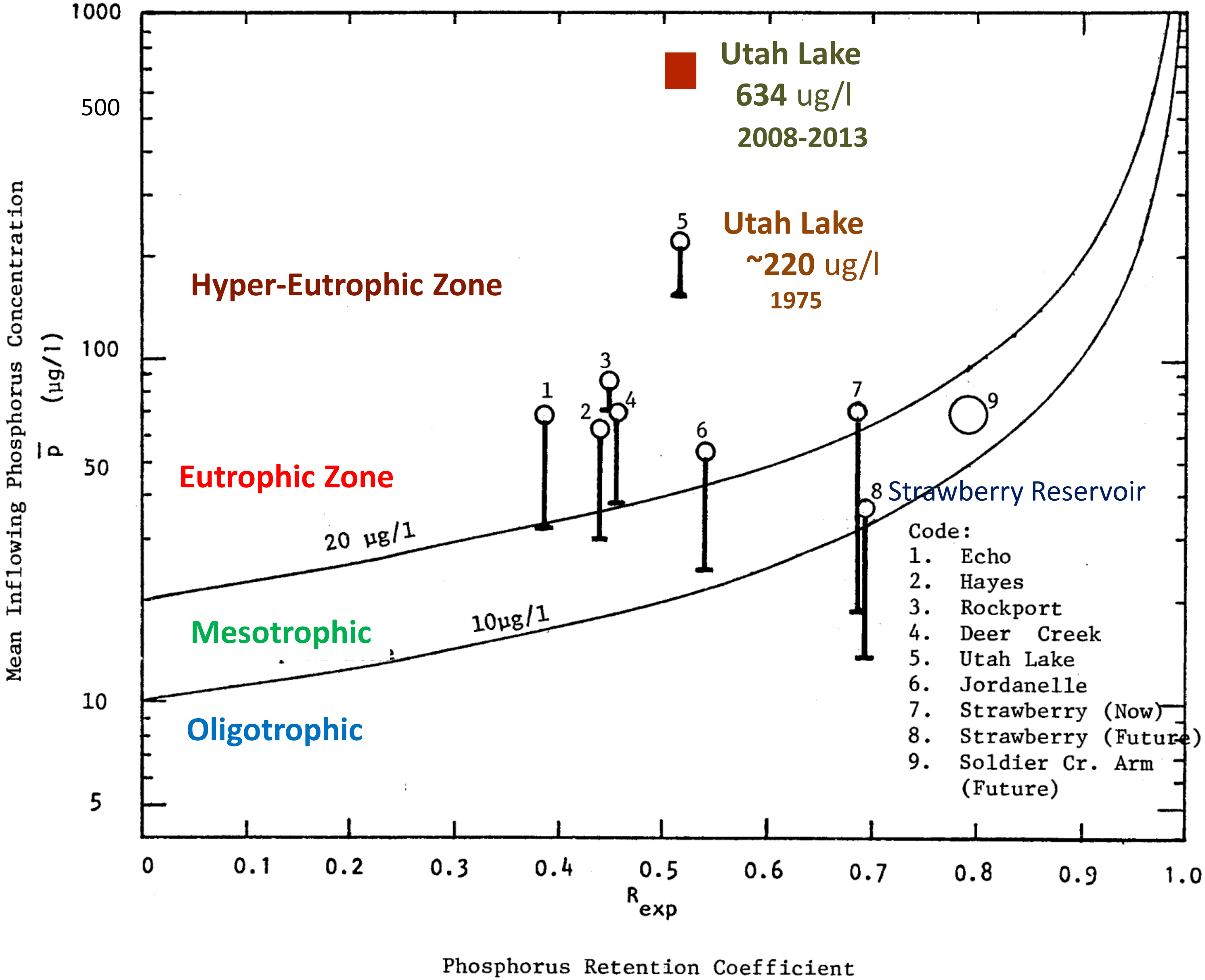
- annual average concentration of phosphorus in inflowing waters.
- lake water residence time and depth.

Predicts the expected lake trophic level

--***but only if phosphorus is the controlling/limiting factor in the lake!***

The next chart also shows results for other lakes about 1975.

x axis points are based on correlation coeffs, that assume lake algae growth is driven/controlled by phosphorus.



Predicted Trophic State based on the Larsen-Mercier Model

Is P limiting?

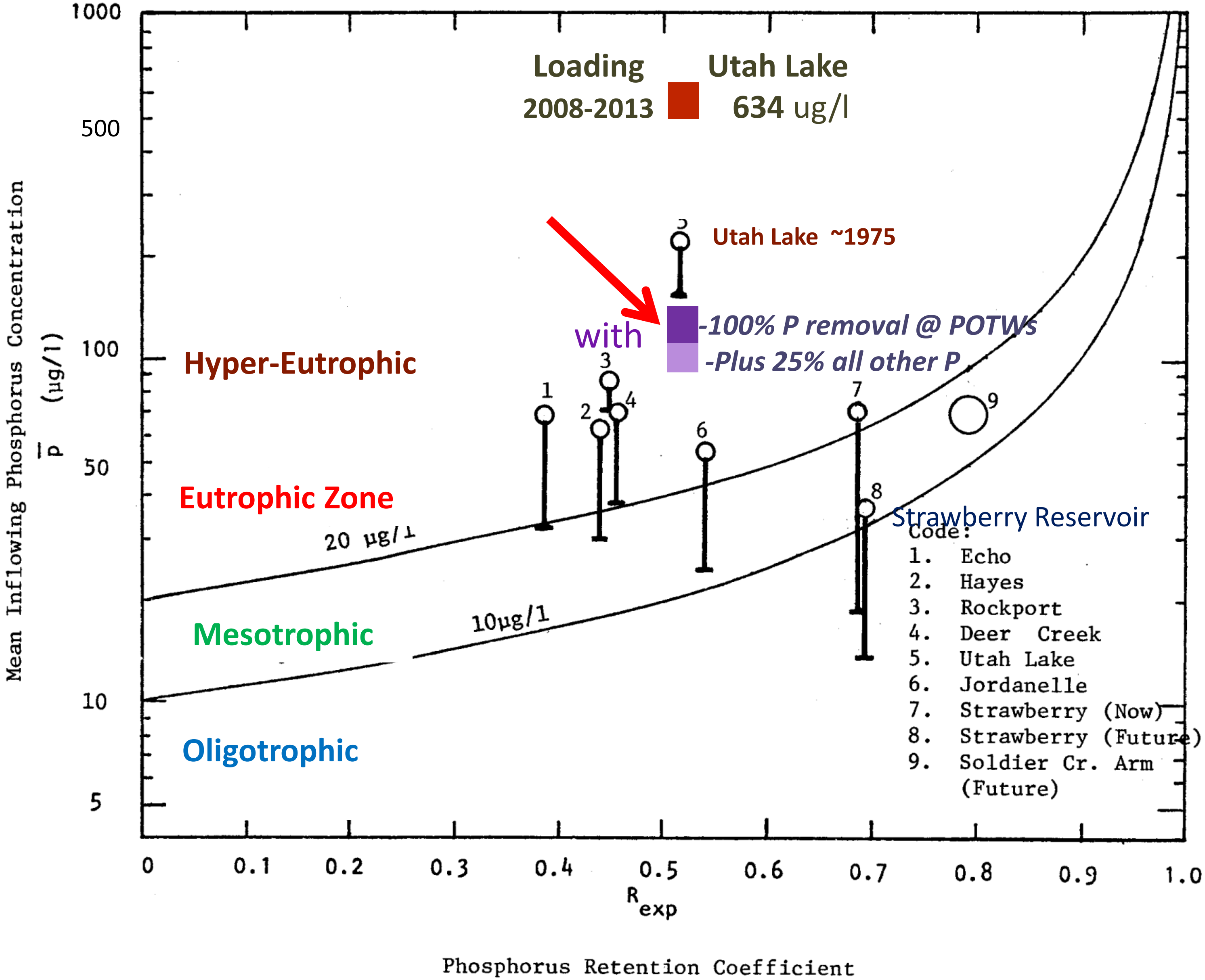
Ans: The L-M model predicts ultra-hyper eutrophic level but the actual condition is just eutrophic.

Therefore: Phos. Is <u>not controlling (not limiting)</u>!

Might P be made limiting? Here's the all-out effort:

- POTWs: About 80% of the Lakes P loading currently comes from them.
  - 90-95% removal at POTWs would cost perhaps \$400-\$600 million in construction costs and tens of millions in annual O&M costs.
- Remove Nonpoint sources (NPS)—
  - As much as 25% of the remaining Phos. <u>might</u> be removed with rigorous NPS controls.
  - Costs would be staggering—likely \$100s of millions to get to a reliable 25% reduction in all other phosphorus loadings to the lake.

Now--What does the Larsen-Mercier model predict from such efforts?



Predicted Trophic State based on the Larsen-Mercier Model

- It’s Impossible to reduce Phosphorus enough to make any difference!

- NOW--The New Big <u>WOW!</u>

- <u>Current Studies:</u>
- Atmospheric Precipitation: Rain, snow, dry deposition
- Concentrations (tentative--8 months of data)

  Phosphorus: about 200 ug/l

  Nitrogen: about 2000 ug/l

  (*These don't yet include dry deposition or summer dusty period.)*

Utah lake:

Annual wet precip: 1 ft/yr

Lake depth: 4 to 9 ft over "normal" wet and dry cycles.

Add in dry deposition to get maybe 30 to 50 µg/l going into the lake.

Momentous Finding:

Atmos. Precip. alone likely delivers eutrophic nutrient loadings to Utah Lake!

(and many other shallow lakes and ponds in the intermountain area)

*This means that Utah Lake algae growth simply **<u>can not</u>** be made to be nutrient-limited; even if only distilled water ran into the Lake!!!*

Looking at the actual nutrient balance information—

Consider the actual phosphorus retention in the Lake (90%).

If the Lake were a "normal" phosphorus-limited lake then P retention would be about 50%--and the Jordan River would have ~300 ug/l rather than the ~50 ug/l found there.

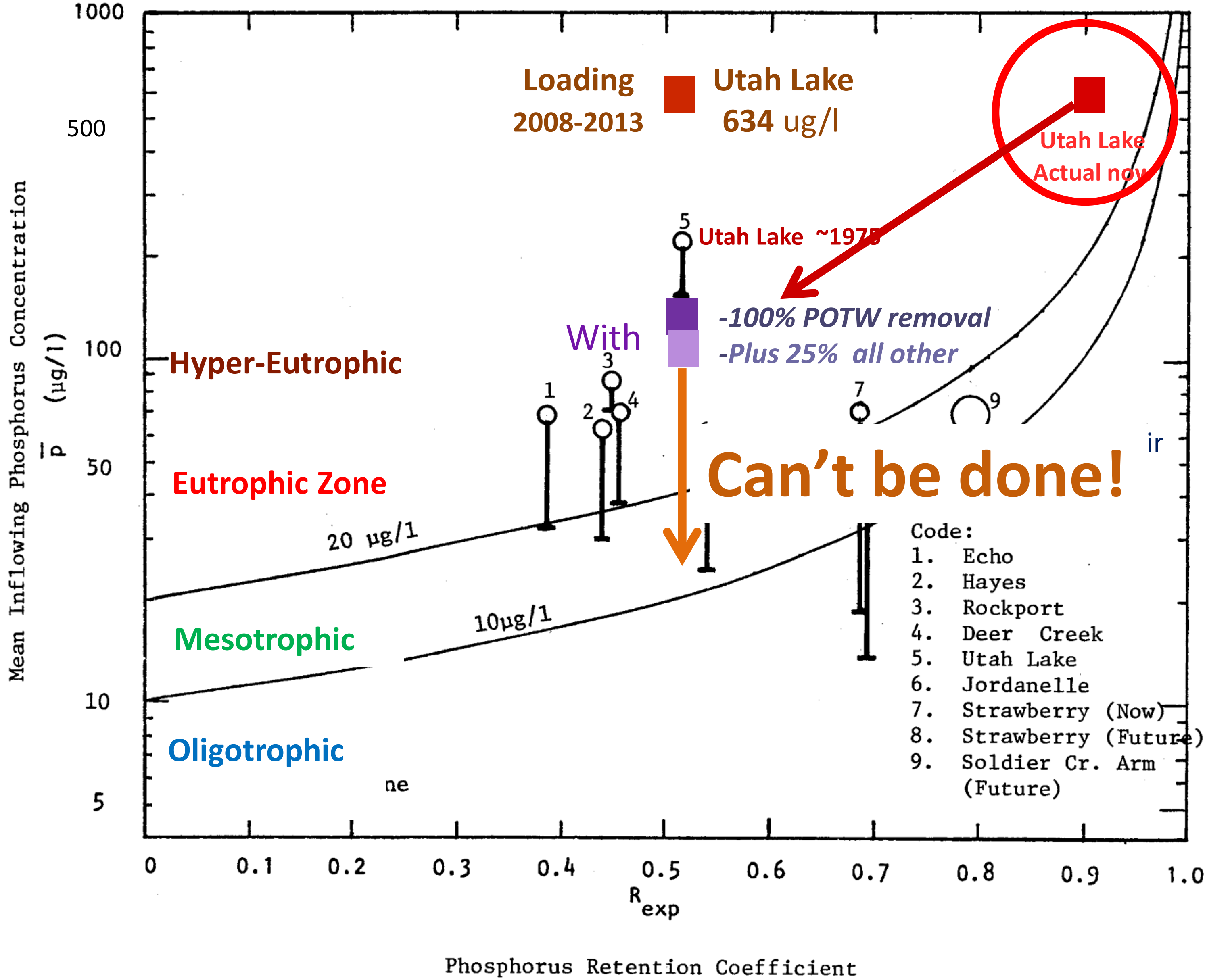
But its actual retention is about 90%--this means there are some rather dramatic, extraordinary, removal mechanisms occurring in the lake:

There are: The main one is precipitation in the mineral precipitates (largely Marl clays) to the bottom sediments.

The "take- away": *Utah Lake is not a normal lake as to phosphorus—it has "unlimited" capacity to trap P into the bottom sediments but the equilibrium seems to be about 50 ug/l in the overlying water--which is a strongly eutrophic level.*

(About 650 ug/l are coming in)

The lake is doing a better job of P removal than any engineered treatment plant could ever do—and it's natural, organic and **Free!**



Predicted Trophic State based on the Larsen-Mercier Model

Again—where is over 90% of the inflowing Phos. going?

Since the Lake has:

- High pH
- High oxygen levels
- Abundant Calcium, Carbonate, Silica and Phosphorus.

Ans—To the sediments via mineral precipitation.

and

Precipitation of Marl & other minerals reduces available soluble phosphorus to relatively low levels—typically 40 to 60 ug/l—regardless of how much is entering the lake!

But even then Phos. is not limiting algae growth most of the time,

that is, even these values would make the lake more eutrophic most of the time than it actually is—if it weren't for Light limitation due to the lakes natural mineral turbidity!

Summary:

1. Light-limitation limits Utah Lake to a natural, moderately eutrophic condition.

2. Phosphorus loading to the lake is some 15 to 20 times larger than that needed to support its eutrophic level and is not limiting to algae growth.

3. Nitrogen loading is also about 15+ times larger than a eutrophic level and not limiting to algae growth.

4. It is extremely unlikely that removal of even all of the phosphorus coming from POTWs, plus 25% of remaining loads, would significantly lower the lakes natural eutrophic algal-growth level.

5. Phosphorus in the Jordan River at the lake outlet is quite low (about 50-60 ug/l) and the result of chemical equilibria with the precipitated sediments in the Lake.

   —and not determined by the amount of phosphorus coming into the lake.

Summary:

1. Light-limitation limits Utah Lake to a natural, moderately eutrophic condition.
   —if this were not the case the lake would be ultra-hyper eutrophic and of horrible quality. In fact, the lake would of likely disappeared (filled in) long ago and just be a swampy margin along an upward extension of the Jordan River.

2. Phosphorus loading to the lake is some 15 to 20 times larger than that needed to support its eutrophic level and not limiting to algae growth. Most of the phosphorus is precipitated and ultimately bound in the lake's sediments.

3. Nitrogen loading is also about 15+ times larger than a eutrophic level. Much of the nitrogen is likely de-nitrified to harmless nitrogen gas at the lake bottom-sediment interface.

4. It is extremely unlikely that removal of even all of the phosphorus coming from POTWs, plus 25% of remaining loads, would significantly lower the lakes natural eutrophic algal-growth level.

5. Phosphorus in the Jordan River at the lake outlet is quite low (about 50-60 ug/l) and the result of chemical equilibria with the precipitated sediments in the Lake.
   —and not determined by the amount of phosphorus coming into the lake.

Conclusion:

It is <u>highly</u> probable that the lake would be essentially the same quality as now, even if every nutrient source were reduced to the highest degree possible—costing many, many hundreds of millions of dollars.

(We would simply be paying a gigantic price to remove phosphorus that is now removed free by mother nature —largely to the bottom sediments)